SCATTERED UV BENEATH PUBLIC SHADE STRUCTURES DURING WINTER

D. J. Turnbull*[1], A. V. Parisi[1] and J. Sabburg[1]

[1]Centre for Astronomy, Solar Radiation and Climate, University of Southern Queensland, Toowoomba, 4350, Australia.

*To whom correspondence should be addressed at: Centre for Astronomy, Solar Radiation and Climate, University of Southern Queensland, Toowoomba, 4350, Australia. Tel. +61 7 46311488; Fax: +61 7 46311530; email: turnbull@usq.edu.au.

†*Abbreviations*: SPF, sun protection factor; SUV, erythemally active UV; SZA, solar zenith angle; UPF, ultraviolet protection factor; UVA, ultraviolet waveband 320-400 nm.

Keywords: Diffuse; scattered; UV; shade; erythema

ABSTRACT

Broadband field measurements were conducted beneath three different sized public shade structures, small, medium and large, during the Southern Hemisphere winter. These measurements were compared to the diffuse UV to quantify the relationship of the UV under and around the shade structures to the diffuse UV. For the shade structures, a relationship between the diffuse UV and the UV in the shade has been provided for clear skies and solar zenith angles (SZA's) of 49^o to 76^o. This allows the prediction of the UV in the shade of these structures if the diffuse UV is known. The ultraviolet protection factors (UPF's) for the three shade structures ranged from 1.5 to 5.4 for decreasing SZA. For the greater SZA's of 70^o to 76^o, the erythemal UV in the shade was 65%, 59% and 51% of that in full sun for the small, medium and large structures respectively. For the smaller SZA's of 50^o to 53^o the erythemal UV in the shade was 35%, 41% and 18% for the small, medium and large shade structures respectively. From this research it can be concluded that the UV radiation levels in the shade in winter could cause erythema and other sun related disorders.

INTRODUCTION

Solar UV radiation plays a considerable role in the health and development of human beings, from initiating the formation of vitamin D to increasing the risk skin cancer and sun-related eye disorders. Due to the phenomena of Rayleigh and Mie scattering in the atmosphere, UV radiation is incident on a horizontal surface in two components, namely direct and diffuse. The direct component is incident in a direct path from the sun, while the diffuse component is scattered and incident from all directions. This diffuse UV may also constitute a significant contribution of the UV exposure to a non-horizontal surface, e.g. to human eyes and skin, as it is incident from all directions and difficult to minimize with the usage of hats and shade environments. As people become more aware about the damaging effects of UV radiation, they will seek shaded environments to reduce their personal UV exposure (1). Although shade does decrease direct UV levels, it is the diffuse UV that can still have high levels. Many people associate the degree of shading with the very welcome perception of a decrease in temperature; meanwhile scattered UV can still reach the shaded skin, which is often unprotected (1).

Local governments provide many and various shaded environments for public use. These structures include gazebos, vegetation, shade cloth, polycarbonate sheeting and various opaque building materials (2). Various studies have been conducted to determine the levels of scattered radiation in different shade environments (e.g. 1 and 3-6). Numerous guidelines on the construction of shade environments have also been developed (e.g. 7-11). These studies have found that over a summer period approximately 60% of the UV that causes erythema was due to the diffuse component, and that different shade environments provide different amounts of protection. Also, at times, the shade may not necessarily always be beneath the structure. At high SZA's, it may be outside the structure as shown in Figure 1. While summer does have the highest levels of direct UV, it is not well documented how the levels of ambient diffuse UV influence the scattered UV beneath and around shaded environments. To the authors' knowledge, no previous research has concurrently measured the diffuse UV on a horizontal plane in full sun and the UV in the shade. This research compares the scattered UV levels beneath three specific shade structures, built by the local council, with that of the diffuse UV on an unshaded horizontal plane for clear skies at a Southern Hemisphere site during winter months. The data gathered is significant, because the relative proportion of scattered UV in shade is at its greatest for the higher solar zenith angles seen during winter.

MATERIALS AND METHODS

Shade Structures. Three different public shade structures were employed in this research and were located at varying public locations around the city of Toowoomba (27.5^{o}S, 151.9^{o}E, 692 m above sea level), Australia. The three structures were chosen so a range of differently sized public shade structures could be investigated. To a first order, the results are applicable to other shade structures of the same approximate dimensions that reduce the amount of sky view by the same approximate amount. None of the shade structures had any surrounding vegetation or other structures. The structures were three different gazebos of varying size and will be referred to as the small, medium and large shade structures. Details of the shade structures are as follows:

- Small Shade Structure: The small shade structure is 2.55 m wide at the sides, 2.28 m high at the eaves and approximately 3.10 m high at the apex. The overhang of the roof is approximately 0.69 m, making the roof area of the small shade structure 15.5 m^2 (Figure 1). This structure was chosen because it is situated between sporting ovals where spectators seek to shade themselves.
- Medium Shade Structure: The medium shade structure is of hexagonal shape with sides measuring 2.16 m wide, 2.11 m high at the eaves, and approximately 3.31 m high at the apex. The overhang of the roof is approximately 0.55 m, making the roof area 19.1 m^2. This structure was chosen due to its location in a park with no other forms of shade available.

- Large Shade Structure: The large shade structure is of an elongated octagonal shape with the longest sides of 2.30 m and the shortest sides measuring 2.10 m. The structure was 2.10 m high at the eaves, 2.85 m high at the apex and had an approximate overhang of 0.69 m. The roof area of the large shade structure was approximately 32.1 m^2. This was chosen because it is located at the corner of a sports field where people will seek shade during sporting events.

The albedo of the grass surrounding the shade structures ranged from 4% in the shade to 6% in full sun, while the albedo of the concrete beneath the shade structure stayed at approximately 10% for shade and full sun. The albedo of the grass was higher than usual; this was caused by dew on the grass.

The tables, seats and underside of the roofs also contributed varying amounts to the UV levels beneath the structure. For the small shade structure the albedo of the table and seats was approximately 11% in the full sun and up to 7% in the shade, with the albedo of the underside of the roof approximately 2%. The albedo of the tables and seats in the medium and large shade structures was approximately 6% in full sun and 4% in the shade, with the underside of the roofs roughly 2%.

When positioned in the centre of the shade structures the amount of sky view obstructed by the shade structures was calculated as 30%, 36% and 42% for the small medium and large shade structures respectively. This percentage was calculated as the area of the roof divided by the area of the roof and the sides.

Shade Structure Radiometry. Several broadband meters were used in this research to measure the solar irradiance and also the illumination. Three broadband sensors were used to measure scattered radiation beneath each of the shade structures; the erythemal

UV (SUV) (12), UVA (320 – 400 nm) and illuminance (lux) were measured. For this research all measurements were taken in the centre of the shade created by the shade structure and at a height of approximately 0.41 m from ground level on the horizontal plane. The height of the measurements roughly approximates young primary school children sitting on the ground. The UV irradiances and illuminance were measured in full sun and then in the shade of the shade structure every 10 min from 9 am to 12 noon. The time between each shade and full sun measurement was less than 1 minute. Two or three clear sky days were utilized to gather data for each shade structure during winter. For the winter measurements, the outside temperature ranged between $9^{o}C$ to $17^{o}C$, relative humidity ranged between 26% to 78% and ozone levels varied between 259 DU to 340 DU.

The UV irradiances were measured with a hand held Robertson-Berger (RB) meter (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) (13) fitted with a UVA detector and an erythemal weighted UV detector. The RB meter was intercompared to a scanning spectroradiometer for UV exposures and temperature variations on a clear day with an SZA between 50^{o} to 66^{o}, the spectroradiometer was fitted with a 15 cm diameter-integrating sphere (model OL IS-640, Optronics Laboratories, Orlando, FL, USA). The uncertainty in the measured UV irradiance is estimated to be of the order of 10% for the RB meter. The spectroradiometer has a double holographic grating (1200 lines mm^{-1}) monochromator (model DH10, Jobin-Yvon, France) connected to a R212 photomultiplier tube (Hamamatsu Co., Japan) temperature stabilized by a Peltier cell temperature controller to $15.0 \pm 0.5^{o}C$. Prior to each series of scans, the spectroradiometer was wavelength calibrated against UV mercury spectral lines and absolute irradiance calibrated against a quartz tungsten halogen lamp (250 W), operated at a constant direct current of 9.500 ± 0.005 A, from a current regulated power supply (model PD36 20AD, Kenwood). This secondary standard lamp calibration is traceable to the National Standards Laboratory at the CSIRO, Lindfield, Australia**.** Relative measurements of visible illuminance were measured with a light meter (model EMTEK LX-102, supplier, Walsh's Co., Brisbane, Australia).

Global and Ambient Broadband Radiometry. Several global and ambient radiometers were used for this research; UVA, SUV and diffuse SUV (UV-Biometer Model 501 Version 3, Solar Light Co.) (14). The UVA and SUV radiometers measure the total global solar irradiance away from any shade. They are mounted on an unobstructed roof of the University of Southern Queensland, Toowoomba. The albedo of the environment surrounding the radiometers is approximately 7%. The differences in the UVA and SUV in full sun between this site and the shade structure sites were less than 10%. The shade structures were located within 7 km of the roof-mounted radiometers. The diffuse SUV radiometer was specifically set up to measure the diffuse erythemal radiation by way of utilizing a shadow band to block the sun as it traverses across the sky. The error associated with the shadow-band of the diffuse SUV radiometer has been measured at approximately 10% with the appropriate correction applied to all of the necessary data. All three radiometers are temperature stabilized to 25^{o}C and were intercompared with the scanning spectroradiometer described in the previous section, with an estimated uncertainty of the order of 10% for each of the radiometers.

RESULTS AND DISCUSSION

UV in the Shade of the Different Structures

The results from the three shade structures used in this research can be generalized to other shade structures with similar sky view fraction, the same SZA range and no surrounding vegetation. The ratios of the SUV, UVA and illuminance in the shade compared to the corresponding full sun are shown in Figures 2 and 3 as a function of SZA for clear skies. SUV and illuminance have been plotted together to show the independence of the two measurements. There is negligible relationship between visible light intensity (illuminance) and UV levels in the shade. The three shade structures are plotted against each other to show how the UV and illuminance levels compare beneath each shade structure. For the higher SZA's (greater than 65^{o}), the erythemal UV ratio beneath the shade structures was 65%, 59% and 51% for the small, medium and large shade structures respectively. UVA in the shade was not as high for the higher SZA's, which was expected due to the decreased scattering at the longer wavelengths, the percentages in the shade were 42%, 41% and 36% respectively. UV levels beneath the large shade structures dropped significantly for the smaller SZA's, with approximately 18% for SUV and 11% for UVA. The small and medium shade structures did not show as large a change at the smaller SZA's, with SUV ratios of 35% and 43%, and UVA ratios at 22% and 24% respectively.

The relative proportion of SUV in the shade of the large shade structure decreases more rapidly than the other shade structures as the SZA decreases, this reduction can be attributed to the larger roof area obscuring more of the sky at the smaller SZA's. When comparing SUV to UVA, the shade ratios for SUV are much higher than for UVA. This occurs due to Rayleigh scattering resulting in increased scattering at the shorter wavelengths. There is also less difference between the shade structures for the UVA shade ratios; this shows that roof area has a more important role in decreasing the scattered SUV than the UVA.

Figure 4a shows the levels of erythemal UV that people situated in the centre of the shade may be exposed to for a changing SZA. Figure 4b shows the UVA irradiances encountered beneath each shade structure and how these levels change as the SZA changes. For UVA, an apparent increase was observed for the large shade structure from 4.3 to 7.7 W/m^2 as the SZA increased; while the small and medium shade structures showed little change, 8.6 to 10.0 W/m^2 and 8.8 to 9.0 W/m^2 respectively, as the SZA increased. The levels of SUV beneath the small and medium shade structures showed a general decrease as SZA increased, 0.14 to 0.08 MED/10 min and 0.13 to 0.04 MED/10 min respectively, whereas the levels beneath the large shade structure increased from 0.06 to 0.08 MED/10 min before eventually decreasing to 0.04 MED/10 min at the larger SZA. The increase in UVA for the large shade structure could be attributed to Mie scattering at the time of the measurements. Small amounts of cloud were observed, but none covered the solar disc. The reduction in SUV for the shade structures was due to the decrease in sky view as the SZA decreased, resulting in diminishing the distance from the centre of the shade to the centre of the shade structure. Specifically, as the shaded area moved to be under the structure with decreasing SZA, there was less sky view.

Ultraviolet Protection Factor (UPF)

The shade ratios were used to obtain the ultraviolet protection factors (UPF's) for each shade structure. These are plotted as a function of SZA in Figure 5. A definite decrease in UPF occurred as the SZA increased for each of the shade structures; this decrease took place due to the increase in the relative proportion of the scattered UV as a result of the larger SZA. The increase in UPF for the large shade structure, at the smaller SZA's, can be attributed to the fact that the centre of the shade received more protection from the roof (decreased amount of sky view) when compared to the other shade structures.

UV in Shade and Diffuse UV

Figure 6 shows the relationship between the diffuse UV in the sun as measured by the roof-mounted radiometers and the scattered UV in the shade measured for each of the shade structures. From this plot the relationships between the diffuse UV and the scattered UV beneath these three shade structures can be obtained for the range of SZA's of 49^o to 76^o.

For clear sky days and SZA's of 49^o to 76^o the relationships are:

Small Shade Structure $$y = -20.0x^2 + 2.5x - 0.03 \quad (1)$$

Medium Shade Structure $$y = 2.6x^2 + 0.7x + 0.001 \quad (2)$$

Large Shade Structure $$y = -7.2x^2 + 0.7x + 0.01 \quad (3)$$

where x is the diffuse UV.

From the relationships obtained for each shade structure, field measurements were conducted and compared against the models for a range of SZA from 56^o to 62^o. For the small, medium and large shade structures variation between the field measurements and those of the models was approximately 6%, 6% and 9%, respectively. The error due to albedo from the various parts of the shade structure has been factored into the models.

CONCLUSIONS

Even in winter the erythemal UV in full sun can be more than adequate to induce erythema, with levels reaching approximately 2.5 MED/Hr during the middle of the day. From this research it can be concluded that these specific shade structures are inadequate for providing the public enough protection against damaging UV radiation for changing SZA. Figure 1 shows the small shade structure used for this research, and how ineffective it is for shading the seats and benches for large solar zenith angles. UPF's are analogous to SPF's (Sun Protection Factor's), the larger the better. With a maximum UPF of 5.4 for the large shade structure, more research is needed to show what effect side-on protection (i.e. trees and shrubs) would have at increasing the UPF's. Although the UPF's for the three shade structures are insufficient, it is still recommended to employ shade as a UV minimisation strategy when outdoors. However, additional sun protection strategies such as hats, appropriate glasses and sunscreen should still be employed, even if seeking shade, for an extended period of time during the winter months. For the shade structures employed in this research a relationship between the diffuse UV and the UV in the shade has been provided for clear skies and SZA's of 49^{o} to 76^{o}. This allows the evaluation of the UV in the shade of these shade structures if the diffuse UV can be measured or modelled.

Acknowledgements – The authors wish to acknowledge Graham Holmes and Oliver Kinder of the Faculty of Sciences, USQ for their assistance.

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Figure Captions

Figure 1. The small shade structure showing the resulting shade area at a high SZA.

Figure 2. Shade ratios for the three shade structures, small (●), medium (■) and large (▲) for the SUV (●, ■, ▲) (left axis) and illuminance (○, □, △) (right axis). The reference is the corresponding irradiance in the full sun.

Figure 3. UVA shade ratios for the shade structures, small (●), medium (■) and large (▲) plotted against SZA.

Figure 4. UV levels encountered beneath the shade structures, small (●), medium (■) and large (▲) as a function of SZA for the (A) erythemal UV and (B) UVA wavebands.

Figure 5. Ultraviolet Protection Factor's (UPF's) for each shade structure, small (●), medium (■) and large (▲) versus SZA.

Figure 6. Scattered UV in the shade of the structures compared to diffuse UV measurements. The measurements are for the small (●), medium (■) and large (▲) shade structures.

Figure 1.

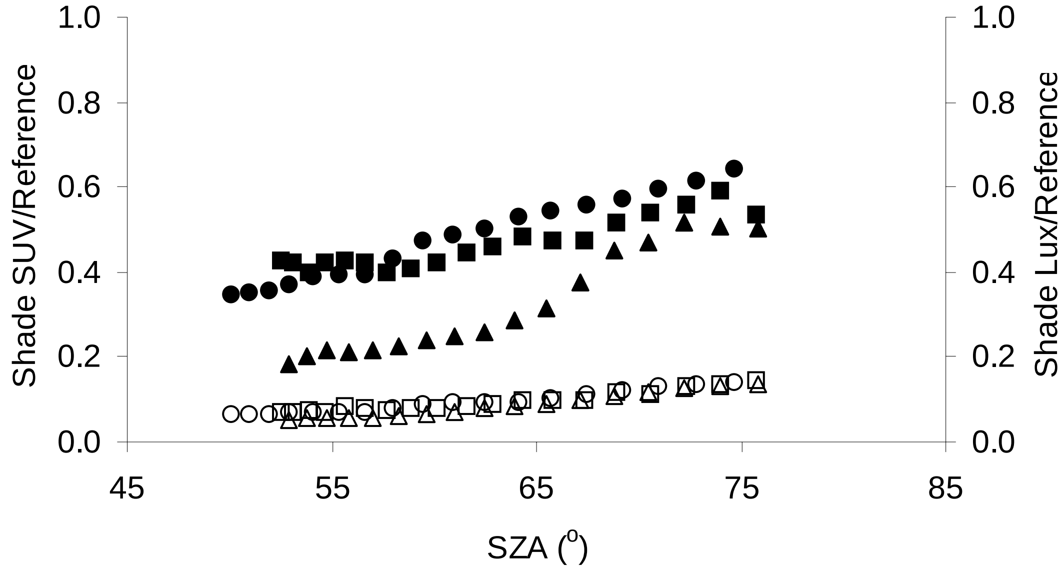

1.0
0.8
0.6
0.4
0.2
0.0
Shade SUV/Reference
Shade Lux/Reference
45
55
65
75
85
SZA (o)

Figure 2.

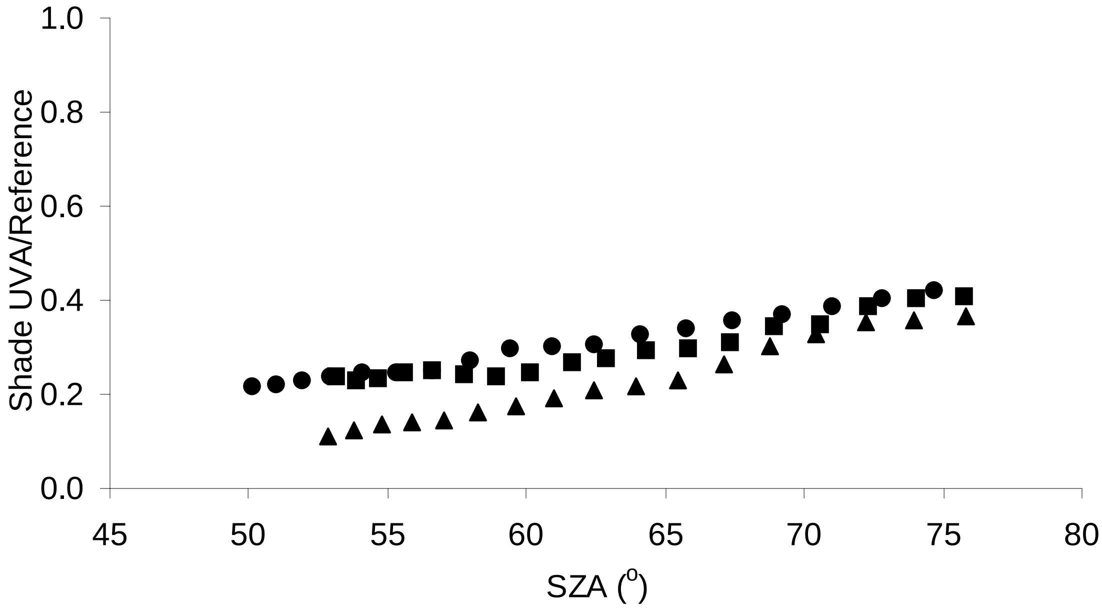
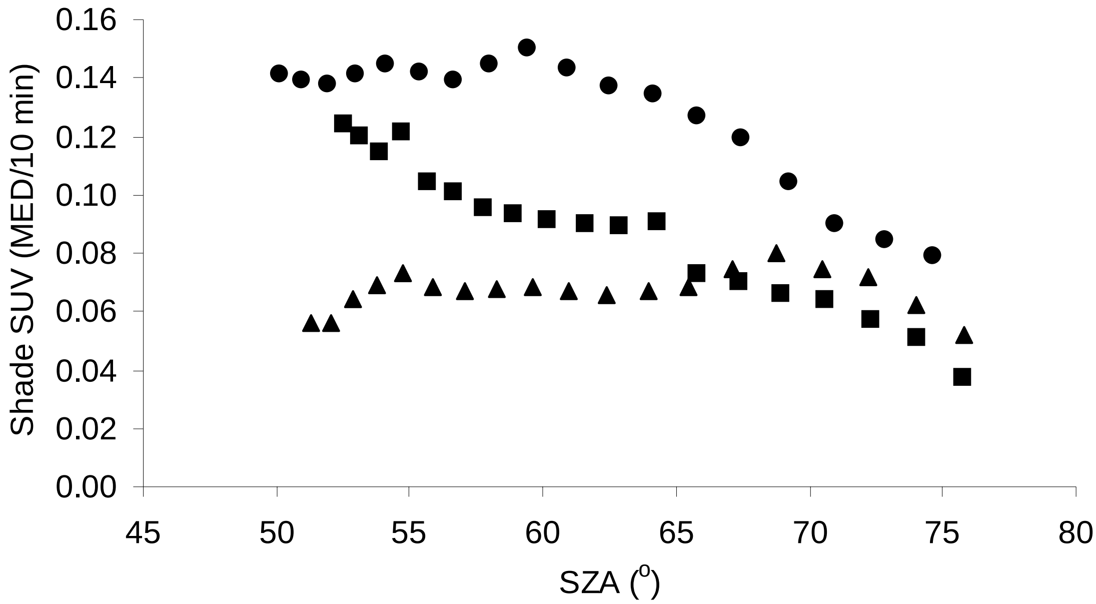


Figure 3.

A


0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Shade SUV (MED/10 min)
45
50
55
60
65
70
75
80
SZA (0)

B

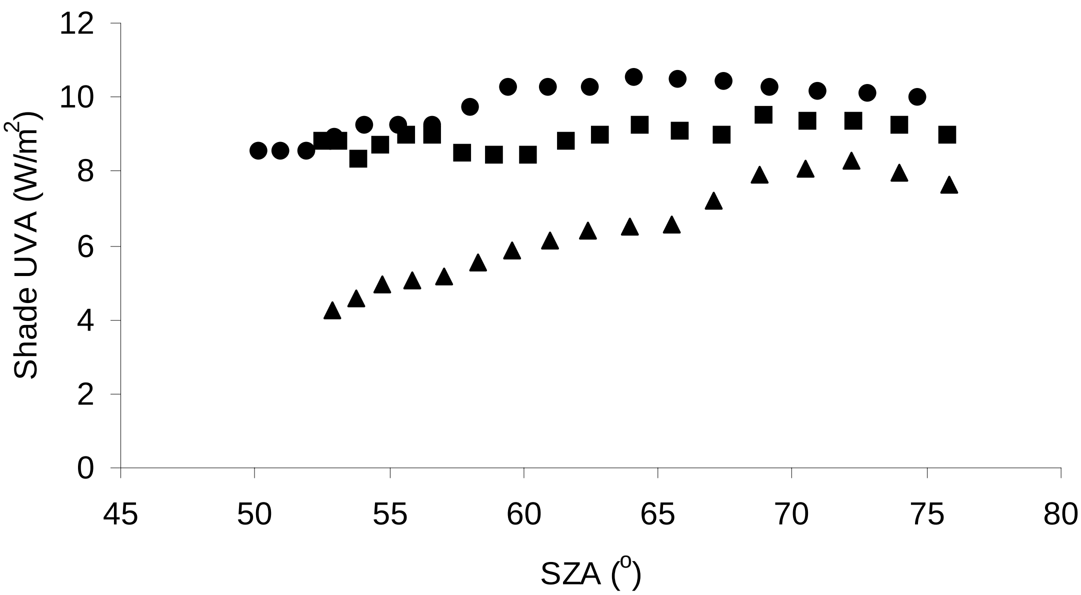

12
10
8
6
4
2
0
Shade UVA (W/m2)
45
50
55
60
65
70
75
80
SZA (0)

Figure 4.

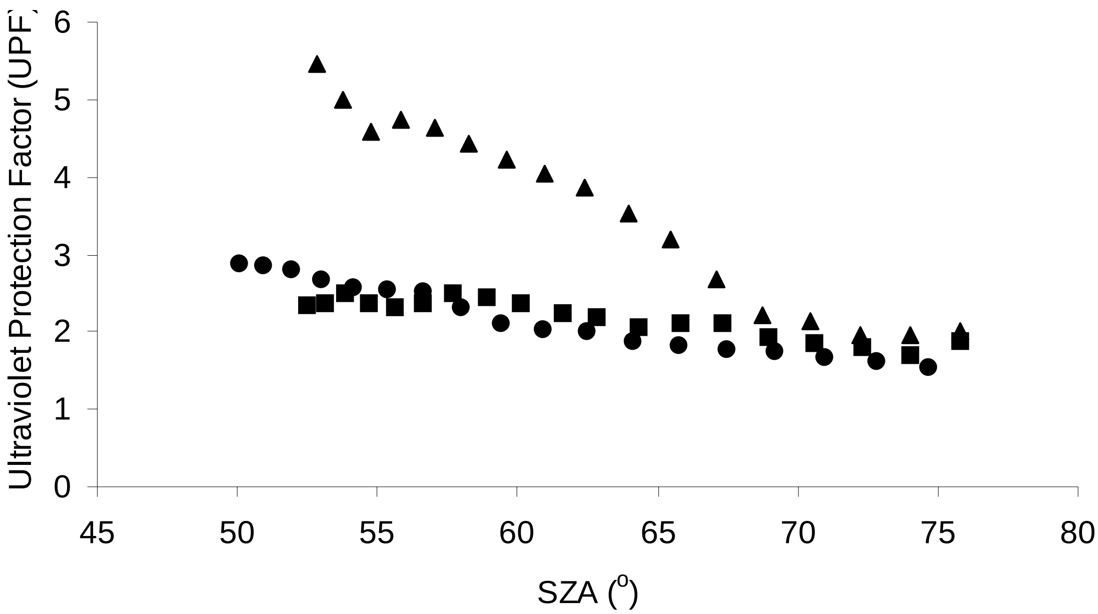

Ultraviolet Protection Factor (UPF)
6
5
4
3
2
1
0
45
50
55
60
65
70
75
80
SZA (^{o})

Figure 5.

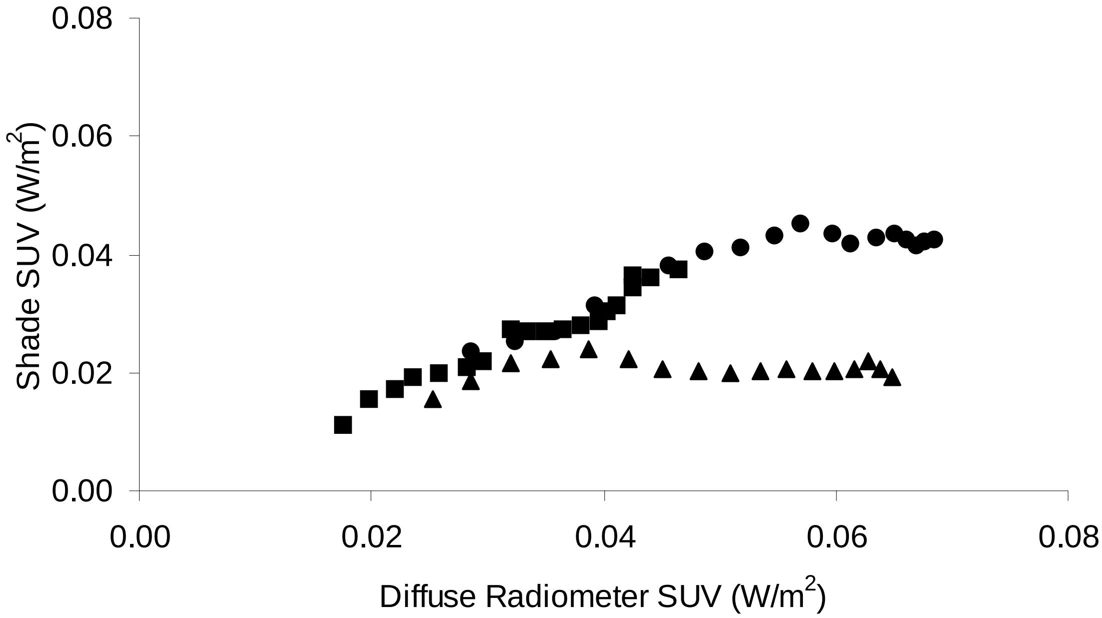

0.08
0.06
0.04
0.02
0.00
Shade SUV (W/m²)
0.00
0.02
0.04
0.06
0.08
Diffuse Radiometer SUV (W/m²)

Figure 6.